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MINISTRY OF SUPPLY

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REPORT No. 1/52

WEAPONS RESEARCH DIVISION

Controlled Fragmentation, XXX.

The application of the grooved charge  
principle to spin-stabilised shell, II

H. Titman & J. W. Taylor  
Safety in Mines Research Establishment, Buxton



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A.R.E. REPORT No.1/52

Controlled Fragmentation XXX. The application of the grooved charge principle to spin-stabilised shell, II

by

H. Titman, B.Sc., Ph.D. and T.W. Taylor, B.Sc.

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SUMMARY

The investigation into the application of the grooved-charge method of controlling fragmentation has been continued to see how well, with a spin-stabilised shell, a charge of H.E. cast into a fluted liner withstands the set-back and centrifugal forces when the shell is fired from a gun. Shells fitted with liners and filled with cast RDX/TNT 55/45 have been fired and recovered; the fragmentation of these shells is compared with that of unused shells. No appreciable difference was found although inspection of three of the recovered shells showed that some set-back of the liner and charge had occurred.

INTRODUCTION

Previous gun trials with shells fitted with fluted liners and filled with H.E. substitute (ref.1) "were thought sufficiently successful to warrant similar trials of shells filled with H.E. in paper liners. It appeared that the whole charge could set-back to a limited extent without destroying the grooving and so its effectiveness for controlling the fragmentation; but any appreciable set-back would interfere with the exploding system and possibly render it unable to give high order detonation of the main charge". The purpose of these trials was therefore to determine whether control of the fragmentation by the fluted liner method was actually impaired by the stresses set up during discharge from a gun.

EXPERIMENTAL

Twenty shells of the type used in the earlier static trials (design DD/L/19716A, see ref.1) were chosen for their constancy both of internal diameter and of length of the parallel-walled portion. Closely fitting liners were constructed from two grades of paper, with the groove depths and angles as shown in Table A1. The two groove depths, 3/16 in. and 1/4 in., were those which gave the best control in the previous trials, and papers of two thicknesses were tried to see if there was any benefit to be gained with the stronger. The reduction of the apical angle to 60° for the flutes of one group of liners was made to test whether the charge was mechanically stronger when grooved at 60° than at 75°, the optimum angle for control.

All shells were filled with RDX/TNT 55/45, because in the static trials this mixture gave satisfactory results and was easy to pour. Details of the exploding and fuzing are given in the Appendix. Some of the shells were filled for natural fragmentation, to serve as control experiments.

The shells were fired for recovery by S. of E., Shoeburyness, details of the firing being given in the Appendix. Only eighteen were recovered; of these, twelve were fragmented at Buxton in the standard sawdust pit and three were opened for visual inspection. Of the twelve shells which were fragmented, eleven detonated satisfactorily; the other, filled for natural fragmentation, did not give full detonation.

RESULTS

The results of the present experiments are not always directly comparable with the previous series (ref.1) since in the present experiments all liners had two staggered rings of flutes whereas some of the previous experiments were with liners fluted along the full length of the parallel portion. A rough comparison can be made, however, if it is assumed that the full-length fragments would have been cut into two by the use of a liner comprising two rings of staggered flutes. On this basis comparison can be made as follows:-

Present seriesPrevious section  
(Report E.185)Type of flute

A	A	Natural fragmentation
B, C	D, F	75°, 3/16 in.
D, E	B	75°, 1/4 in.
F	C	60°, 1/4 in.

Natural fragmentation - There was an interval of three years between the manufacture of the two special batches of shells used in the static trials and for the present series, and it was found that the natural fragmentation of the latter batch was much coarser than that of the former. In the earlier experiments the average results showed that about 12 per cent. of the weight of the shell appeared as 27 fragments weighing 1 oz. or more whereas, as the average in the present series, there were 69 fragments in this class involving about 29 per cent. of the weight. The fragments down to 1 oz. from shell A3 are shown in Fig.1.

The mean value of the  $\bar{c}$  parameter (ref.2) for the shells used for the static trials is 0.98, whilst for the two shots in the present series the mean value is 0.54. Even on the small number of experiments carried out, this difference is significant. It should be noted that the later shells were, on average, about 6 oz. heavier than those of the earlier batch, but it is not likely that such a small increase in weight could account for the large difference in fragmentation.

It was thought possible that strains resulting from the gun trials might have modified the fragmentation of the present batch, and two spare unused shells were therefore filled and fragmented (see Table A10). The  $\bar{c}$  parameter was 0.52, practically the same as for the gun-fired shell which, it follows, had not been affected in the way suggested.

It is clear therefore that, although the shells of the two batches were supposedly the same, the natural fragmentation characteristics were very different. One shell from each batch was sent for metallurgical examination and the report by R. Jeffrey is given in Appendix II. There were differences in the properties of the steels which would account for the differences in fragmentation.

Liners with 3/16-in. deep flutes having 75° angle - Good control of the fragmentation was achieved; the number of fragments weighing down to 1 oz. was increased to about 100 involving about 47 per cent. of the weight of the shell. A photograph of the fragments from shell C11 is given in Fig.2, and comparison with Fig.6 and Section F of Report E.185 would suggest that the control was actually somewhat better with the fired shells than with the unfired. Certainly the control was not lessened by the stresses suffered during propulsion and stoppage in the sea and there was no significant difference between the control achieved with the thick and thin paper liners.

Liners with 1/4-in. deep flutes having 75° angle - Since the 3/16-in. groove was adequate for controlling the fragmentation, it was to be expected that a 1/4-in. groove would produce over-cutting of the shell wall. The fragments from shell D12 are shown in Fig.3 and by comparison with Fig.2 it is seen that the shape of the fragments is worse and that over-cutting has occurred. They are not so clearly cut, so rectangular nor quite so large as from shell C11; the weight classification, however, is too coarse to indicate this quantitatively. Comparison with Fig.5 and Section B of Report E.185 shows that similar over-cutting occurred in the static trials and that control of fragmentation of the gun-fired shells was not inferior to that of the unfired shell.

Liners with 1/4-in. deep flutes having 60° angle - The fragments from shell F20 are shown in Fig.4. It will be seen that some over-cutting still occurred even though the angle was more acute. The control, however, is as effective as that shown in Section C of the static trials, and 54 per cent. of the total weight of the shell appeared in fragments weighing down to 1 oz.

Internal examination of fired shells - Because of the risk of cutting into the H.E. filling it was not possible to section any of the live shells and so to recover the liners intact for comparison with those of the earlier series which were filled with H.E. substitute. An attempt was therefore made to melt out the explosive with steam, but this was only partially successful as it was found that after a little of the explosive had been removed the steam then attacked and disintegrated the exposed liner. It was, however, possible to see how far the liner had moved from its original position in the shell.

Three shells, B6, D14 and F19, were examined and it was found that in one case the set-back was imperceptible whilst in the other two shells it was 0.5 and 1.0 in. It is not known whether any crumpling of the liner had been caused at the base, but since control of the fragmentation was on the whole so good it is inferred that little, if any, deformation of the flutes had occurred.

#### CONCLUSIONS

1. In the course of the full investigation, two batches of shell have been used and there were differences in the steels which caused large differences in the natural fragmentation of the two lots. The controlled fragmentation of the two lots, however, is not disturbed by the difference between the steels; that of the gun-fired shell is as good as that obtained with unfired shells in the static trials. The amount of set-back that occurs, therefore, does not interfere with the control of fragmentation.
2. It is not possible from these trials to assess the effect of the set-back on the exploder system. This information could only be obtained from fragmentation in flight trials. It is noteworthy, however, that the only charge which failed to detonate correctly was one for natural fragmentation, in which there was no liner, and hence but little set-back.
3. A paper liner 0.007 in. thick with 75° flutes is sufficiently strong to withstand the stresses caused by set-back and spin. It is not necessary either to use thicker paper or to strengthen the liner by using 60° flutes.

#### REFERENCES

1. H. Titman and T.W. Taylor; Controlled fragmentation XXVIII. Application of grooved-charge principle to spin-stabilised shells, I; Buxton Report E.185
2. Empirical relationships for use in comparing results of fragmentation trials, II. Weight distribution of fragments; Buxton Report D.32, R.C.388

See also A.R.E. Report No. 35/50

APPENDIX, E.193

Details of shell and initiating system

SHELL To design DD/L/19716A, with screw-in nose adaptor

Stencilled O.B. Proc. Q 5635  
O.B. 900

Stamped Q.F. 4" H.E.  
To DD/L/19716A  
WITH MOD  
SCREW IN NOSE BUSH  
FA. FS. RL.3/49  
O.B. 900

EXPLODER Two 14 dr. C.E. pellets

FUZE Either adaptor DD/L/17240 or adaptor D2/L/1819/E/364 modified  
Initiation by No.6 aluminium cased detonator

FILLING Filled at Buxton with RDX/TNT 55/45

LINER For controlled fragmentation; design as specified below

---

EXPERIMENTAL ESTABLISHMENT, SHOEBOURNE

Details of recovery trial

OBJECT Recovery trial. Carried out 15th February 1950  
Authority:- S.O.B., as det. O.B. Proc. Q.6223  
O.B. Reqs. 651 and 782

GUN 4-inch Mark 16

CHARGE NF/S 164-048, weight 10-10-0, to give M.V. of 2700 f.s.  
approximately and 17 tons per square inch

PROJ Shell Q.F. H.E. 4-inch, design DD/L/19716A filled RDX/TNT 55/45;  
fitted dummy gaine, dummy C.E. pellet, adaptor to design  
D2/L/1819/E/364 and plug representing fuze N.2 Mark 1

FIRING Shell to be fired, under precautions, over water for recovery,  
at any convenient Q.E. After recovery, plugs to be unscrewed,  
and any water to be removed from fuze cavity. Shell to be  
re-plugged and forwarded to S.M.R.E. (Buxton) for static  
fragmentation

TABLE A1 - Specifications of filled casings

Paper liners of length 5.4 in. consisted of 2 staggered sections each having 16 V-flutes of apex angle 75° or 60°, depth 1/4 in. or 3/16 in.

Identification number	Series	Description of liners		
		Type of paper	Depth of flutes in.	Apex angle °
1- 5	A		No liner	
6- 8	B	Thin	3/16	75
9-11	C	Thick	3/16	75
12-14	D	Thin	1/4	75
15-17	E	Thick	1/4	75
18-20	F	Thin	1/4	60

TABLE A2 - Weights of shells (including driving band) and fillings

Round number	Weight of empty shell			Weight of explosive filling		
	lb.	oz.	dr.	lb.	oz.	dr.
A 3	25	12	3	3	6	14
A 5	25	12	7	3	7	0
B 8	25	12	11	3	2	10
C10	25	13	2	3	3	6
C11	25	12	13	3	2	9
D12	25	11	6	3	1	3
D13	25	12	14	3	0	13
E15	25	13	0	3	0	5
E16	25	11	8	2	15	14
F18	25	12	4	3	2	1
F20	25	11	0	3	1	10
A21	25	11	12	3	6	4
A22	25	10	10	3	6	12

Weight of driving band 1 lb. 1 oz. 7 dr.

TABLE A3 - Summary of numbers, weights and percentage weights of fragments

Fragments down to, oz.	A3	A5	B8	C10	C11	D12	D13	E15	E16	F18	F20
Number											
8				1		1	1		1		
6				3		5	4	7	2	1	3
4	3	4		35	38	26	36	32	21	40	36
2	15	14	31	101	103	78	104	87	99	90	102
1	65	73	98	204	197	206	207	212	220	181	192
1/2	218	208	212	314	310	368	333	343	381	295	329
1/4	424	417	359	465	467	548	477	499	533	454	501
1/8	665	623	532	813	751	892	743	840	881	783	847
1/25	1106	1063	913	1105	1068	1200	985	1111	1144	1052	1126
1/50	1430	1417	1193	1505	1565	1269	1470	1450	1326	1472	
1/100	1764	1857	1577								
Weight, oz.											
8				7.1		6.7	7.5		8.2		
6				16.4		23.9	20.0	32.5	12.2	6.7	12.4
4	12.4	18.4		112.1	113.0	83.5	114.6	103.8	67.3	119.5	106.9
2	41.6	42.0	90.9	203.2	199.5	151.7	203.2	179.7	171.5	214.9	196.5
1	107.3	121.4	117.9	276.4	266.9	244.3	277.2	267.9	257.4	279.4	259.3
1/2	214.3	215.2	258.6	314.9	307.5	302.8	322.4	315.1	313.9	320.3	308.4
1/4	286.1	289.7	309.5	341.6	336.4	335.7	349.1	342.6	341.6	349.1	338.6
1/8	331.5	326.1	340.6	366.5	357.5	362.0	368.4	367.1	366.0	372.6	363.1
1/25	365.1	357.6	367.4	374.7	366.6	371.1	375.2	375.1	373.9	380.1	371.2
1/50	374.6	367.9	375.5	379.3	372.9	376.4	379.2	380.3	378.2	383.9	376.2
1/100	379.5	374.0	381.2								
Percentage weight											
8				1.78		1.70	1.89		2.07		
6				4.14		6.06	5.05	8.20	3.11	1.69	3.14
4	3.13	4.66		28.33	28.58	21.20	28.99	26.24	17.09	30.26	27.16
2	10.54	10.64	22.99	51.35	50.45	38.51	51.40	45.41	43.51	54.43	49.92
1	27.19	30.74	45.01	67.52	62.02	70.10	67.71	65.31	70.76	65.89	
1/2	54.28	54.49	65.43	79.59	77.77	76.86	81.54	79.66	79.66	81.12	98.36
1/4	72.49	73.35	78.32	86.33	85.09	85.23	88.29	86.62	86.68	88.43	86.03
1/8	83.98	82.57	86.18	92.62	90.42	91.89	93.17	92.79	92.89	94.37	92.26
1/25	92.49	90.54	92.96	94.71	92.72	94.22	94.87	94.82	94.89	96.27	94.31
1/50	94.90	93.14	95.01	95.86	94.31	95.56	95.88	96.14	95.96	97.25	95.59
1/100	96.13	94.68	96.44								

## Cumulative tables of numbers and weights of fragments

TABLE A4 - Natural fragmentation, Series A

Fragments down to oz.	Number			Weight			Percentage weight		
	A3	A5	Av.	A3 lb.oz.dr.	A5 lb.oz.dr.	Av. lb.oz.dr.	A3	A5	Av.
4	3	4	4	12 6	1 2 7	15 7	3.13	4.66	3.90
2	15	14	15	2 9 10	2 10 1	2 9 14	10.54	10.64	10.59
1	65	73	69	6 11 5	7 9 7	7 2 6	27.19	30.74	28.97
1/2	218	208	213	13 6 4	13 7 4	13 6 12	54.28	54.49	54.39
1/4	424	417	421	17 14 2	18 1 12	17 15 15	72.49	73.35	72.92
1/8	665	623	644	20 11 8	20 6 2	20 8 13	83.98	82.57	83.28
1/25	1106	1063	1085	22 13 2	22 5 10	22 9 6	92.49	90.54	91.52
1/50	1430	1417	1424	23 6 10	22 15 14	23 3 4	94.90	93.14	94.02
1/100	1764	1857	1811	23 11 7	23 6 0	23 8 12	96.13	94.68	95.41

TABLE A5 - Controlled fragmentation, Series B

All fragments down to oz.	Number B8	Weight B8 lb. oz. dr.	Percentage weight B8
2	31	5 10 14	22.99
1	98	11 1 14	45.01
1/2	212	16 2 9	65.43
1/4	359	19 5 8	78.32
1/8	532	21 4 9	86.18
1/25	913	22 15 6	92.96
1/50	1193	23 7 8	95.01
1/100	1577	23 13 2	96.44

TABLE A6 - Controlled fragmentation, Series C

Fragments down to oz.	Number		Weight		Percentage weight	
	C10	C11	C10 lb. oz. dr.	C11 lb. oz. dr.	C10	C11
6	1		7 1		1.78	
4	3		1 0 7		4.14	
2	35	38	7 0 2	7 1 0	28.33	28.58
1	101	103	12 11 3	12 7 7	51.35	50.45
1/2	204	197	17 4 6	16 10 15	69.85	67.52
1/4	314	310	19 10 15	19 3 7	79.59	77.77
1/8	465	467	21 5 10	21 0 6	86.33	85.09
1/25	813	751	22 14 8	22 5 8	92.62	90.42
1/50	1105	1068	23 6 12	22 14 10	94.71	92.72
1/100	1453	1505	23 11 5	23 4 14	95.86	94.31

Cumulative tables of numbers and weights

TABLE A7 - Controlled fragmentation, Series D

Fragments down to oz.	Number		Weight		Percentage weight	
	D12	D13	D12 lb.oz.dr.	D13 lb.oz.dr.	D12	D13
6	1	1	6 11	7 7	1.70	1.89
4	5	4	1 7 14	1 3 15	6.06	5.05
2	26	36	5 3 8	7 2 10	21.20	28.99
1	78	104	9 7 11	12 11 4	38.51	51.40
1/2	206	207	15 4 5	17 5 3	62.02	70.10
1/4	368	333	18 14 12	20 2 7	76.86	81.54
1/8	548	477	20 15 11	21 13 2	85.23	88.29
1/25	892	743	22 9 15	23 0 7	91.89	93.17
1/50	1200	985	23 3 2	23 7 3	94.22	94.87
1/100	1565	1269	23 8 7	23 11 3	95.56	95.88

TABLE A8 - Controlled fragmentation, Series E

Fragments down to oz.	Number		Weight		Percentage weight	
	E15	E16	E15 lb.oz.dr.	E16 lb.oz.dr.	E15	E16
8		1		8 2		2.07
6		1		8 2		2.07
4	7	2	2 0 7	12 3	8.20	3.11
2	32	21	6 7 13	4 3 5	26.24	17.09
1	87	99	11 3 10	10 11 7	45.41	43.51
1/2	212	220	16 11 14	16 1 5	67.71	65.31
1/4	343	381	19 11 2	19 9 14	79.66	79.66
1/8	499	533	21 6 10	21 5 9	86.62	86.68
1/25	840	881	22 15 1	22 14 1	92.79	92.89
1/50	1111	1144	23 7 1	23 5 15	94.82	94.89
1/100	1470	1450	23 12 5	23 10 3	96.14	95.96

TABLE A9 - Controlled fragmentation, Series F

Fragments down to oz.	Number		Weight		Percentage weight	
	F18	F20	F18 lb.oz.dr.	F20 lb.oz.dr.	F18	F20
6	1		6 11		1.69	
4	1	3	6 11	12 6	1.69	3.14
2	40	36	7 7 8	6 10 15	30.26	27.16
1	90	102	13 6 14	12 4 8	54.43	49.92
1/2	181	192	17 7 6	16 3 6	70.76	65.89
1/4	295	329	20 0 4	19 4 7	81.12	78.36
1/8	454	501	21 13 2	21 2 10	88.43	86.03
1/25	783	847	23 4 9	22 11 2	94.37	92.26
1/50	1052	1126	23 12 1	23 3 3	96.27	94.31
1/100	1326	1472	23 15 15	23 8 3	97.25	95.59

TABLE A10 - Natural fragmentation, Series A. Unfired shells

All fragments down to oz.	Number			Weight			Percentage weight		
	A21	A22	Av.	A21 lb.oz.dr.	A22 lb.oz.dr.	Av. lb.oz.dr.	A21	A22	Av.
2	18	10	14	2 10 15	1 10 3	2 2 9	10.90	6.65	8.78
1	73	79	76	7 7 0	7 9 12	7 8 6	30.19	30.96	30.58
1/2	198	194	196	13 0 8	12 6 10	12 11 9	52.88	50.50	51.69
1/4	430	421	426	18 4 12	17 7 13	17 14 5	74.25	71.14	72.70
1/8	627	683	655	20 7 9	20 6 8	20 7 1	83.07	83.01	83.04
1/25	1086	1163	1125	22 9 6	22 9 4	22 9 5	91.64	91.85	91.75
1/50	1308	1408	1358	23 0 1	23 0 8	23 0 5	93.34	93.70	93.52
1/100	1612	1743	1678	23 4 12	23 5 4	23 5 0	94.53	94.90	94.72

APPENDIX 2Report E.193 - Metallurgical examination of two shells

R. Jeffrey.

Sample shells from the two batches were submitted for examination. The shells were marked OB 8370/A9 and OB 900 respectively.

A ring was cut from the middle of each shell for analysis, hardness tests and microscopical examination. The analyses were carried out by the Bragg Laboratory, Sheffield.

Chemical CompositionFirst batch  
OB 8370/A9Second batch  
OB 900

Carbon	0.406	0.425
Manganese	1.43	1.24
Silicon	0.17	0.14
Sulphur	0.038	0.042
Phosphorus	0.041	0.041
Nickel	0.23	0.10
Chromium	0.09	0.04
Molybdenum	0.24	0.04
Copper	0.23	0.21

It will be seen that shell OB 8370/A9 contains more manganese, nickel and molybdenum than shell OB 900; including silicon and chromium, the total is 0.60 per cent. greater.

Hardness Tests, V.D.H. No. OB 8370/A9 - 273, OB 900 - 217

Microscopical Examination

The structure of the two shells are shown in Figs.5 and 6. Shell OB 900 (Fig.6) was normal and had a grain size equal to A.S.T.M. No.4. The other shell OB 8370/A9 had an aocicular structure (Fig.5) which suggested that the shell had been rapidly cooled during manufacture or that the steel had a tendency to air harden from normalising or forging temperatures. This structure was present throughout the shell. A test piece of the steel normalised at 875°C. showed a finer though similar structure and the aocicular characteristic was only removed by annealing. The structure, therefore, is due to the composition of the steel and not to any deficiency in heat treatment during manufacture.

Conclusions

Shell OB 8370/A9 had an abnormal aocicular structure which is attributed to the greater amounts of manganese, nickel and molybdenum, particularly the latter. The greater amounts of these elements will also account for the high hardness of the shell.

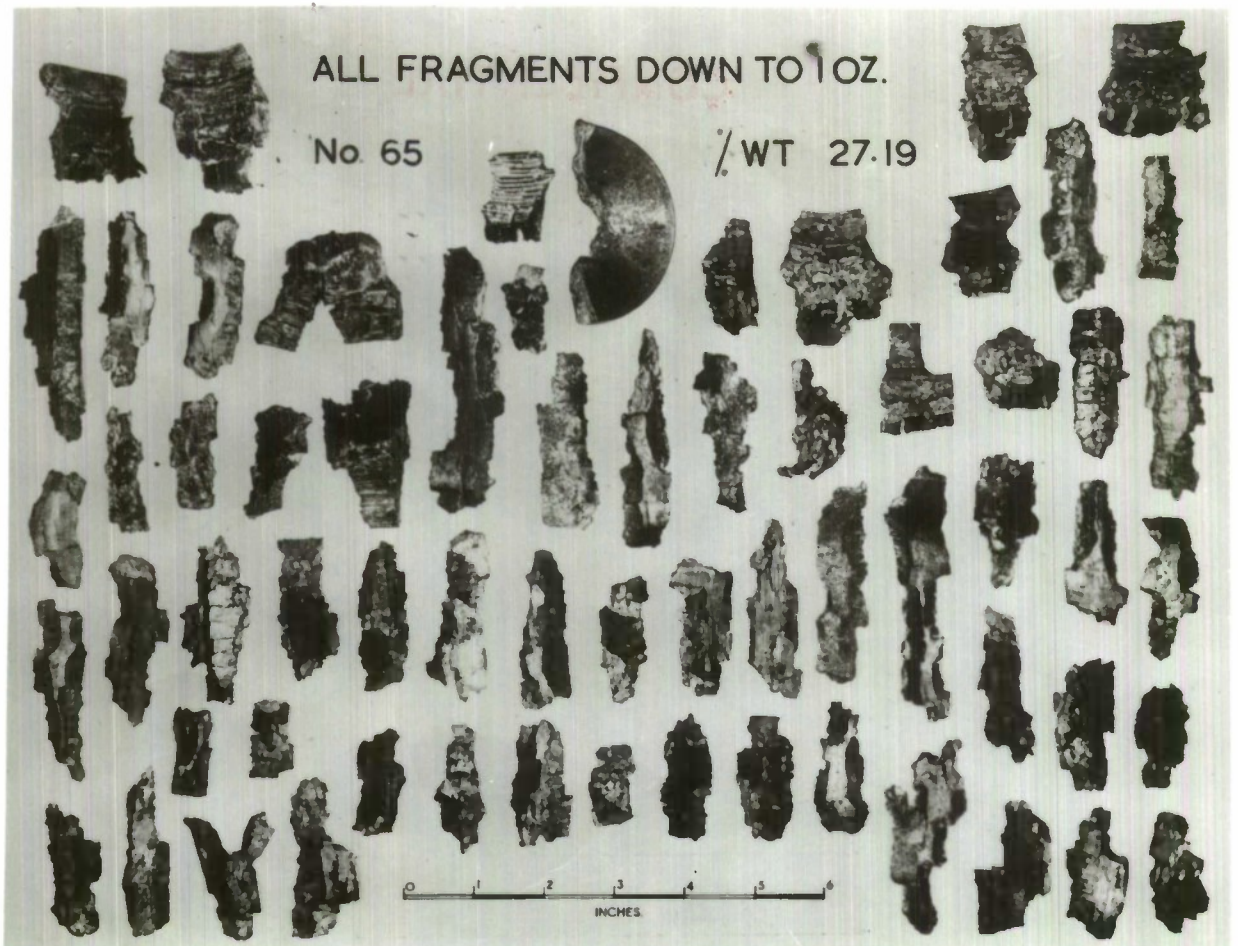


Fig.1-Natural fragmentation

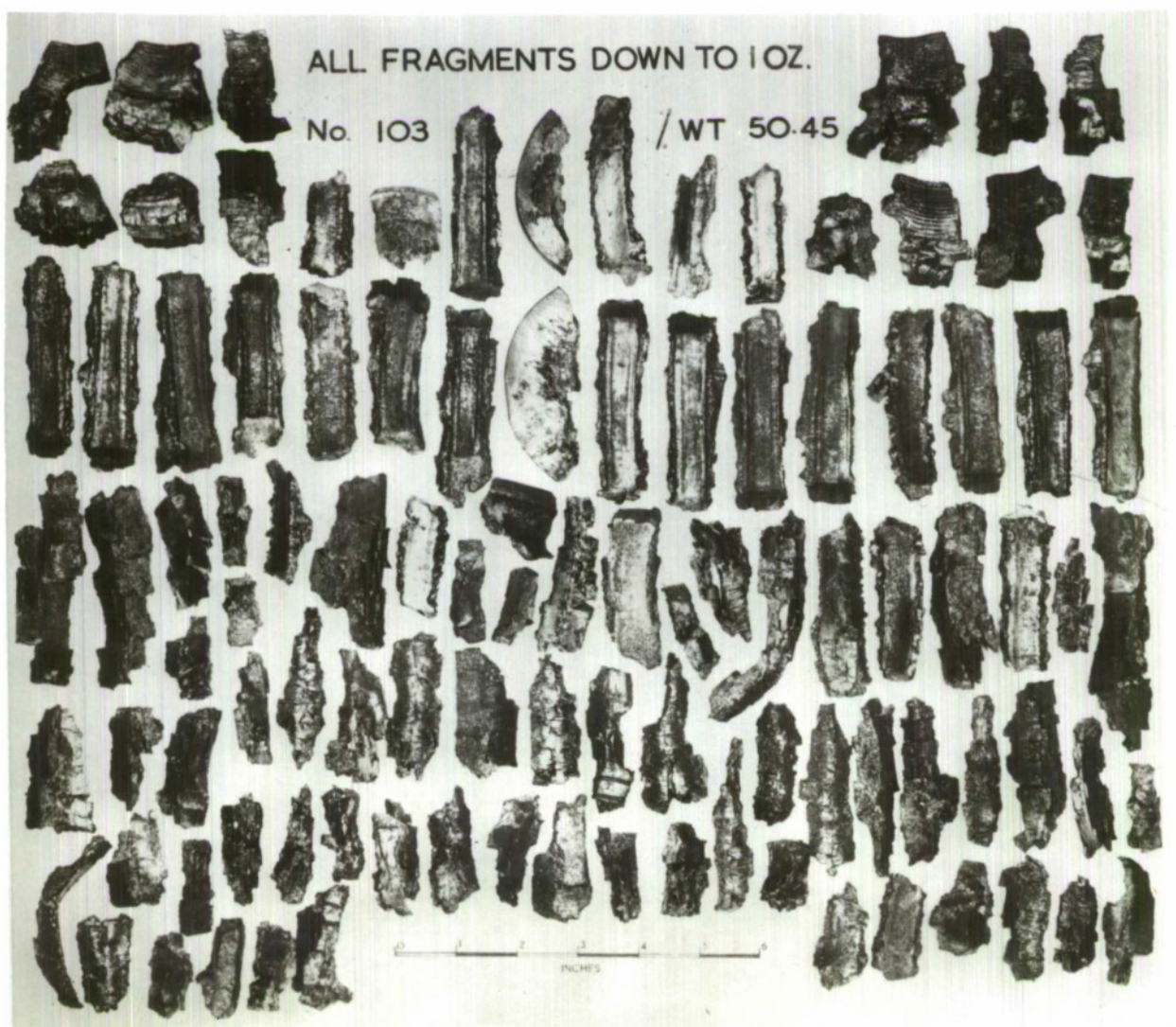


Fig.2-Flutes  $\frac{3}{16}$  in. deep, apex  $75^\circ$

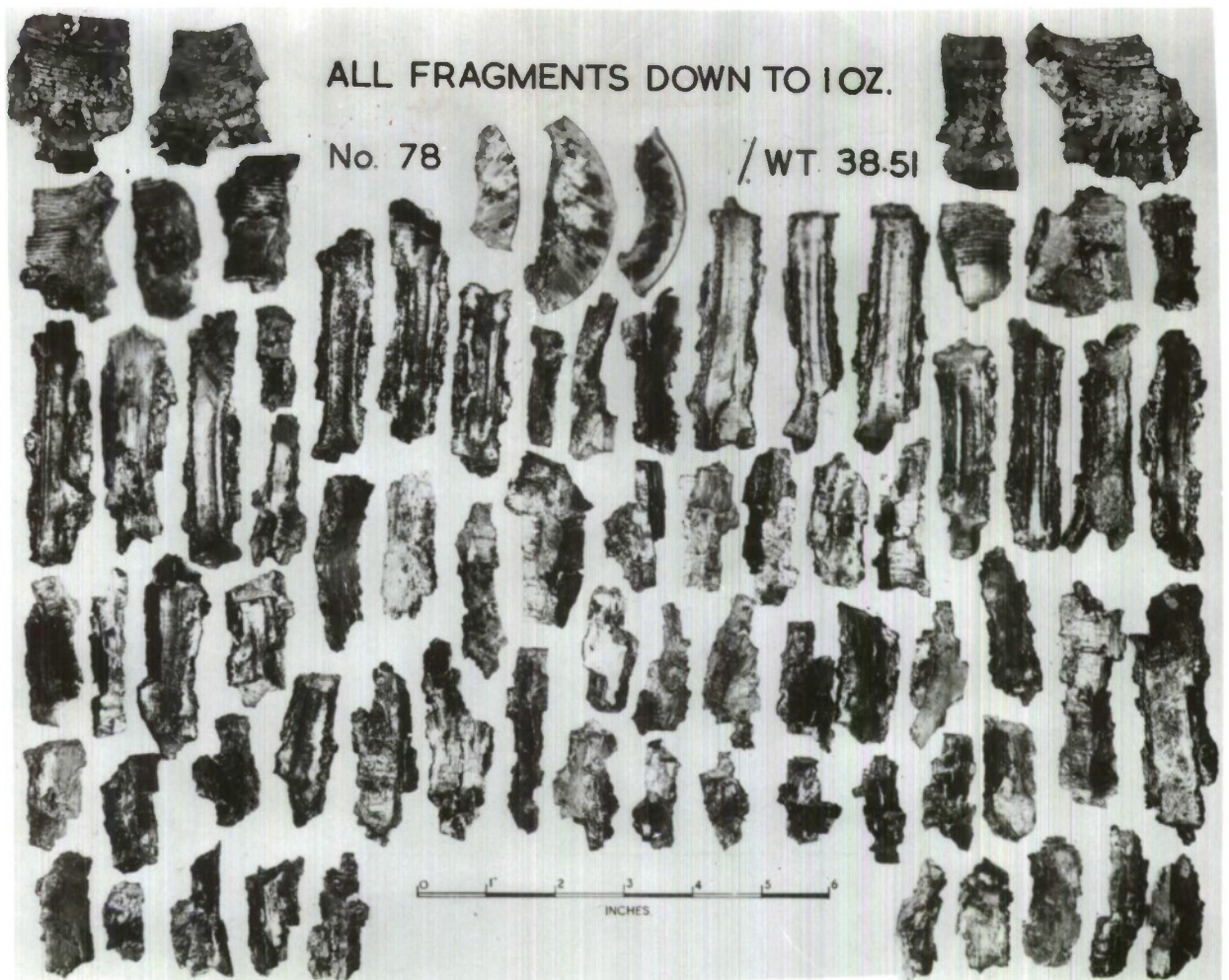


Fig.3- Flutes  $\frac{1}{4}$  in. deep, apex  $75^\circ$

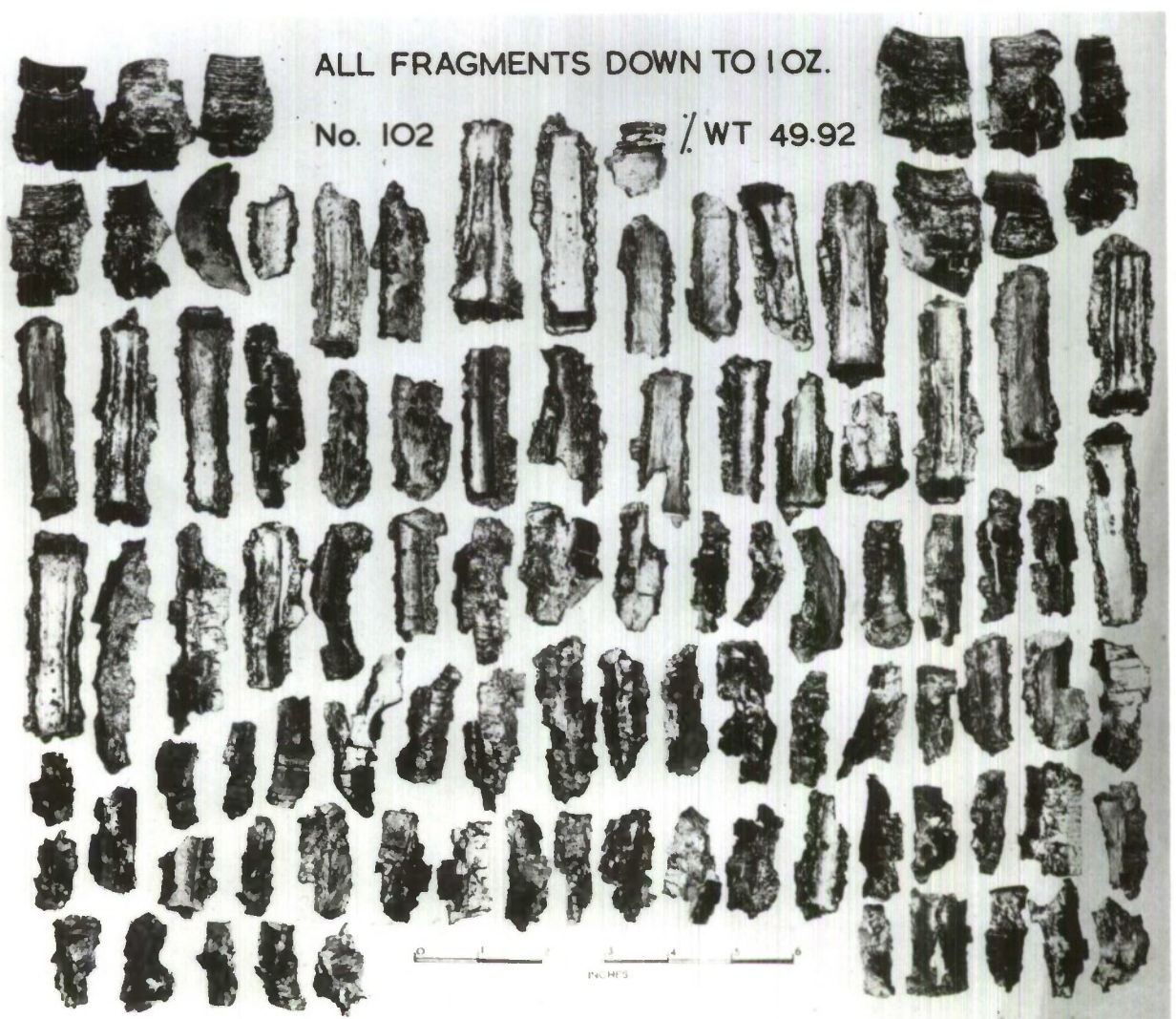


Fig 4- Flutes  $\frac{1}{4}$  in. deep, apex  $60^\circ$

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Fig.5—Microstructure of shell O.B. 8370



Fig. 6—Microstructure of shell O.B. 900



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